A Brief History of Electrical Engineering Education

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Abstract—Electrical engineering curricula made their first appearance in the U.S. in the early 1880's as options in physics that aimed to prepare students to enter the new and rapidly growing electrical manufacturing industry. As this industry developed, so did electrical engineering education, and within a decade made a place for itself as an equal among the older engineering departments. The curricula that evolved followed the needs of the industry, and before World War I were concentrated largely on the properties of dc and ac circuits and equipment and associated systems of power distribution.

Before World War I, little graduate work was carried on, and what passed in academic institutions for "research" was typically advanced testing. The standard career pattern was to receive a B.S. degree and then obtain a job where one could learn how practical electrical work was done. After World War I, developments in broadcasting and communication led to the appearance of communication options within electrical engineering departments. Concurrently, students having a special interest in teaching or in research were increasingly encouraged to obtain the master's degree. However, the numbers who did so were small, and practically no electrical engineers sought a doctor's degree. For example, at the Massachusetts Institute of Technology in 1925 there was only one member of that large faculty who held an earned doctorate, while the background of about half of the faculty consisted of a bachelor's degree plus practical experience. Under these circumstances research performed in academic institutions was in most cases superficial, although here and there some significant work was carried on by an unusual professor.

When World War II came along and brought into being such new electrical and electronic techniques such as radar, microwaves, control systems, guided missiles, proximity fuses, etc., the electrical engineers were caught unprepared. As a group they had neither the fundamental knowledge required to think creatively about these new concepts, nor the research experience to carry through. Thus most of the great electrical developments of the war were produced not by engineers, but rather by scientists, particularly physicists who had turned engineers for the duration.

In the decade after the war, electrical engineering education went through a complete transformation. Prewar courses were drastically revised. Increased emphasis was placed on fundamentals, including particularly emphasis on physical and mathematical principles underlying electrical engineering. These results were achieved by reducing the time devoted to teaching engineering practice, by eliminating subjects such as surveying that were of little concern to electrical engineers, and by reducing the concentration on 60-cycle power. In addition, master's programs were developed that were direct extensions of the revised bachelor's program, and in time the master's degree became the recommended degree goal of the student who desired to follow a career in technical engineering.

Concurrently, the doctor's degree became the objective of those who planned a career in academia or of research in industry, or who wanted training superior to that of their many classmates working for the master's degree. With government funds available, programs of student-faculty research developed on many campuses that were the equal of the research being carried on in the best industrial laboratories.

The combined effect of curriculum changes, more students carrying on graduate work, the existence of university research laboratories of the highest caliber with this research led by well-trained faculty aided by doctoral and master's candidates, has completely changed both the character and intellectual level of electrical engineering on the campus. This is illustrated by the fact that in a 1969 survey of a representative group of major high technology firms, 82 percent agreed with the statement that "Engineers now learn enough science and mathematics so that they can adequately fill positions once occupied only by physicists." If another world emergency should arise, the electrical engineers will this time be ready to carry their share of the leadership.

Manuscript received January 1, 1976.
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Introduction

THE HISTORY of electrical engineering education parallels the development of the electrical industry, particularly of the electrical manufacturing industry. The electrical experimenters, inventors, and innovative entrepreneurs such as Edison, Morse, Weston, Brush, Bell, Sprague, Westinghouse, Thomson, etc., who developed the early practical applications of electrical phenomenon, were either trained in related disciplines such as physics, chemistry, mechanics, etc., or were self-trained resourceful tinkerers possessing elements of genius. However, once industrial applications had been developed to the point where there were electrical installations to be designed and electrical equipment to be manufactured and sold in substantial volume, a need existed for trained electrical engineers to design, test, and improve this equipment as well as to supervise production, installation, and maintenance. Thus the history of electrical engineering education over the years has paralleled the developments taking place in electrical manufacturing.

The Beginnings of the Age of Electricity

The first important practical application of electricity was the telegraph, invented by Samuel F. B. Morse, who was an artist by profession. The key date is 1844 when telegraph service between Baltimore and Washington was inaugurated. Also, more or less with the introduction of the telegraph, electrical systems came into use for such applications as fire and burglar alarms and for railway signaling. Important as these events were, they did not create much of a demand for electrical engineers since the instruments to be manufactured were simple, and were inexpensive as compared with the value of the outside plant.

In the mid-1870's, Alexander Graham Bell, a speech teacher, began to experiment with the electrical reproduction of sound, and in March 1876 he was issued the basic patent on the telephone. An early model of his telephone system was exhibited in Philadelphia at the Centennial Exhibition in June 1876.[1] In spite of patent litigation and the need for making further technical improvements, some 778 telephones were in service by August 1877, and another application of electricity had been found.

In 1884 a group of 71 individuals who were active in the application of electricity to useful ends gathered together in New York City and formed the American Institute of Electrical Engineers. These charter members included Weston, Brush, Sprague, Edison, Thomson, Bell, Sperry, and Professor Cross.

The first industrial application of electrical *power* was the illumination of streets, auditoriums, and other large spaces by the electric arc. A commercially successful arc light system was developed in the period 1875–1879 by Charles Brush of Cleveland, culminating in the installation in 1879 by the California Electric Company of San Francisco of two dynamos supplying a total of 22 arc lights. This was the first electric central station in the world, and it was an immediate commercial success. Within six months additional equipment had been installed that supplied over 50 arc lights. During the next two years Brush central stations were established in a number of American cities including New York, Boston, and Philadelphia. Additional companies quickly entered the field; of these the most successful was the Thomson–Houston Electric Co. of Lynn, MA.[2]

During the period 1877–1880, Edison developed an incandescent lamp system[3] as an alternative to the previously used gas lights and kerosene lamps. In 1882 a central station embodying the Edison principles was completed on Pearl Street in New York City, and sold electric lighting on a commercial basis that was competitive with gas lighting. This installation was a financial success, and incandescent lighting was soon being employed in an increasing number of cities. The firm created to exploit the Edison system was the Edison General Electric Co.

The resulting widespread availability of electrical power provided by the Edison lighting system created a market for electric motors, a market which Frank Sprague was the first to exploit in a major way beginning in 1884. The electric motor soon made it unnecessary for industrial plants to use a steam engine, or to be located near water power.

The development of satisfactory electric motors opened up the possibility of electric traction. The first entirely satisfactory electric railway system was that built by Sprague in Richmond, VA.[4] It became fully operational in 1888 and made horse cars forever obsolete.

Around 1885 attention began to be given to the possibility of using alternating current (ac) instead of direct current (dc) in systems of electrical power. The transformer had been invented a few years earlier and although there was some initial confusion as to the best way to use it, there was an appreciation of the fact that the ability to transform voltage held promise of economies. The ac motors were being developed, including commutator motors, and also Tesla's induction motor for which Westinghouse had purchased the American patent rights. A meter for measuring ac power was also invented around this time by Shallenberger. The essentials for an ac system of electrical lighting and power accordingly became available.

In 1886, George Westinghouse formed the Westinghouse Company as a spinoff from his Union Switch and Signal Company for the special purpose of concentrating on ac possibilities. This was in spite of the fact that Westinghouse's advisors almost to a man felt that ac had little future in competition with dc.

Under the encouragement of Westinghouse, William Stanley installed an ac incandescent lighting system in Great Barrington, MA, in 1886, which involved transformers that were considered the heart of ac long-distance transmission. In the following years additional ac central lighting systems were installed by Westinghouse Electric Company in various parts of the United States, and also by the Thomson–Houston Company. The Edison interests reacted vigorously against the use of ac but were unsuccessful in their efforts. The controversy between ac and dc systems subsided in 1892 when the Edison General Electric Company united with the Thomson–Houston Company, already in the ac business, to form the General Electric Company. Thomas Edison felt so strongly on the subject of ac that after the merger he resigned as director of the General Electric Company and for the rest of his life had nothing to do with it.

[1] See Hounshel paper, this issue.

[2] Other pioneer developers of arc lighting systems included Edward Weston, founder of the instrument company bearing his name, and Elmer Sperry of gyroscope fame.

[3] This employed the Edison 3-wire direct-current system.

[4] See Condit paper, this issue.

Around 1890 the subject of how to utilize the power that was potentially available from Niagara Falls became a lively topic. After a number of studies the decision was made in 1893 to use ac for transmitting power to Buffalo, NY, 20-mi distant, and bids were put out in October 1893 for the first three generators. Westinghouse insisted on the use of 25 Hz rather than the originally specified $16\frac{2}{3}$ Hz and won the initial contract. Later orders were divided between Westinghouse and General Electric. The first generators went into service in 1895. As things developed, much of the power was used locally for electrochemical industries that sprang up adjacent to the power houses, but 5000 kW of the initial power was transmitted to Buffalo in a two-phase 2200-V system.[5]

Thus by 1900 an electrical industry had come into being and was a part of life in the United States. There was the telegraph and the telephone. The country's streets, stores, homes, and buildings were being illuminated by electric lighting, using either arc or incandescent lights as the occasion required. Power distribution systems had been developed that made possible the economic transmission of electrical energy over substantial distances, and electric motors were coming into use in large numbers. The electric street car was in common use. Some of the enthusiasts of the time exclaimed that the age of steam was over, and the age of electricity had arrived!

Early Electrical Engineering Curricula

The flowering of the electrical industry in the decade 1875–1885 not only established electrical engineering as a challenging profession, but also created the need for educational programs that would prepare young men for careers in this new and exciting field of activity.

The first educational program in the U.S. designed to train young men for a career in the new electrical industry was established at the Massachusetts Institute of Technology (M.I.T.) in 1882. It was under the friendly sponsorship of Physics Professor Charles Cross, head of the Physics Department, who had become interested in the applications of electricity. The 1882–1883 M.I.T. catalog describes it as "an alternative course in physics ⋯ for the benefit of students wishing to enter upon any of the branches of electrical engineering." In 1884 this course of study was renamed electrical engineering, although still under the sponsorship of the Physics Department where it remained until 1902, when a separate Department of Electrical Engineering was established at M.I.T.

Similar programs quickly followed at other institutions. In 1883, Cornell University announced a program in electrical engineering sponsored by Physics Professor William Anthony. Subsequently, in 1885 when Thurston became head of engineering at Cornell, he took an interest in electrical engineering and worked cooperatively with the Physics Department. In time a separate department of electrical engineering came into existence.

In 1886 an electrical engineering department was organized at the University of Missouri. The University of Wisconsin organized such a department in 1891. When Stanford University enrolled its first freshman class in 1891 the catalog stated that students interested in electrical engineering should enroll in mechanical engineering, but the 1892–1893 catalog shows a functioning but very small (one man) separate electrical engineering department.

[5] See Belfield paper, this issue.

In 1881, the year before the M.I.T. course in electrical engineering was first announced, only four of all the graduates that M.I.T. had produced since its first commencement in 1868 were working in the field of electrical engineering. Thus the first electrical engineering programs were created more in anticipation of what was expected to develop than to meet an already existing need. However, events quickly justified the supporters of these programs, and by the 1890's enrollment in them was as great if not greater than in the older fields of civil and mechanical engineering. Thus at M.I.T. 27 percent of all the institute graduates in 1892 were electrical engineers. Again, at Stanford the "pioneer" class of 1895 included more electrical engineers than either mechanical engineers or civil engineers.

The electrical content of the early electrical engineering curricula was minimal. Engineering knowledge about electrical phenomena was limited, there were few if any textbooks, and laboratory facilities were meager. For example, Harris J. Ryan, long-time head of electrical engineering at Stanford, once stated that when he entered Cornell as a freshman in 1883 the electrical engineering laboratory of the university was "little more than the electrical section of the physics laboratory of that day." The "little more" was one direct current generator built by Professor William Anthony in 1874 and exhibited at the Centennial in Philadelphia. At M.I.T. the laboratory situation was only slightly better until the completion of the 40 000 square-foot Augustus Lowell Laboratory of Electrical Engineering in 1902 financed by a memorial gift of \$50 000 made by the sons and daughters of Augustus Lowell.

M.I.T.'s 1882 curriculum for electrical engineers is given in Table I and clearly shows its close relationship to physics. It is interesting to note the absence of electives and the considerable number of required courses in the humanities and social sciences. During the following years, until well after World War I, the general pattern of electrical engineering curricula gradually changed with emphasis on dc and ac circuits, on the characteristics of motors, generators, transformers, distribution systems, etc., and on the measurement of electrical quantities. A few courses were commonly available as professional electives dealing with such subjects as communication systems, batteries, electrical railways, illumination, etc. Some schools offered a course in "wireless" telegraphy, but this was the exception rather than the rule.

Undergraduate Curricula Between the Wars

After World War I, new factors began to influence electrical engineering. The vacuum tube had become a device that could not be ignored. The broadcasting industry came into being and grew rapidly. Radio communication expanded as the possibilities of the higher frequencies became understood, and water cooled tubes were developed that could produce substantial power, including power at these "short-wave" frequencies. Furthermore, the telephone industry exploited new possibilities created by the vacuum tube, and not only steadily increased the technological level of its activities, but became of growing importance as an employer of electrical engineers.

As a consequence of these new factors, communication options (sometimes formal, often informal) began to appear in electrical engineering curricula in the 1920's and were selected by an increasing number of students. These communication programs were typically built around the interests of one or two younger faculty members, many of whom had been radio

TABLE I
ELECTRICAL ENGINEERING CURRICULUM M.I.T. 1882

FIRST YEAR

First Term	Second Term
Algebra continued.	Plane and Spherical Trigonometry.
Solid Geometry.	General Chemistry.
General Chemistry.	Qualitative Analysis.
Chemical Laboratory.	Chemical Laboratory.
Rhetoric.	English History.
English Composition.	English Literature.
French.	French.
Mechanical Drawing.	Mechanical Drawing.
Free Hand Drawing.	Free Hand Drawing.
Military Drill.	Military Drill.

SECOND YEAR

First Term	Second Term
Physics, Lectures.	Physics, Lectures.
Physical Laboratory, General Laboratory Work and Experimental Acoustics.	Physical Laboratory, General Laboratory Work, Acoustics, Simple Applications of Electricity.
Analytic Geometry.	Differential Calculus.
Shopwork, Carpentry; Wood and Metal Turning.	Shopwork; Wood and Metal Turning.
Descriptive Astronomy.	Physical Geography.
English History and Literature.	English History and Literature.
German.	German.
	General Physics, Theoretical Acoustics.

THIRD YEAR

First Term	Second Term
Physical Laboratory, Special Methods in Photometry.	Physical Laboratory, Electrical Measurements and Testing.
General Physics, Electricity, Photometry.	General Physics, Electricity.
Integral Calculus.	Advanced Physics, Memoirs, etc.
Applied Mechanics.	History of Physical Sciences.
Mechanical Engineering, Theory and Practice of Steam and other Engines.	Applied Mechanics.
Mechanical Laboratory, Use of Dynamometers, Indicators, etc.	Mechanical Engineering.
Constitutional History.	Mechanical Laboratory.
	Political Economy.
	German.

FOURTH YEAR

First Term	Second Term
Physical Laboratory, Electrical Testing and Construction of Instruments.	Physical Research.
General Physics, Applications to Telegraph, Telephone, Electric Lighting, etc.	General Physics, Applications of Electricity.
Photography.	Advanced Physics, Memoirs, etc.
History of Physical Science.	Principles of Scientific Investigation.
Mechanical Engineering Laboratory.	Advanced Mathematics.
Applied Mechanics, Thermodynamics, Hydraulics, etc.	Note.--The student is advised to take Advanced German.

hams in their earlier days, and who entered into the rapidly expanding field of what we now call electronics with an enthusiasm which they transmitted to their students. The result was that the communication options in electrical engineering grew steadily in popularity through the 1920's and 1930's.

Graduate Study in Electrical Engineering 1882-1945

Graduate study in electrical engineering beyond the bachelor's degree developed only very slowly in the period before World War I. This is illustrated by the data in Table II. The general attitude during this period was that upon obtaining a bachelor's degree the electrical engineering student should find a job and get practical experience. In fact, until well into the 1920's there was little in the way of organized instruction in electrical engineering beyond the bachelor's degree available on the typical campus, and the question could legitimately be raised as to whether many of the professors of that era were really qualified to offer *bona fide* graduate work.

Before World War I the large manufacturing concerns, notably General Electric and Westinghouse, had developed special programs for the initiation of college graduates into the world of electrical engineering. These company-sponsored activities were regarded by students as highly desirable stepping stones in the development of careers in electrical engineering. In public utilities, fresh college graduates were commonly assigned to the drafting board or to construction projects and thereby gained practical experience in a different manner. During this period many of the better organized employers felt that a college man with a master's degree was less useful to them than a man with a bachelor's degree, since in their opinion the former had wasted a year by hanging around college and thereby avoiding facing up to the real world.

TABLE II
MASTER'S AND DOCTOR'S DEGREES AWARDED IN SOME REPRESENTATIVE INSTITUTIONS

	Master's Degrees[1] Total in 5-year periods					Doctor's Degrees Total in 5-year periods				
Period	MIT	Stanford	U Cal (B)	Cal Tech	Cornell	MIT	Stanford	U Cal (B)	Cal Tech	Cornell
1900-04	2	1	0	+	6	0	0	0	+	1
1905-09	4	3	0	+	8	0	0	0	+	1
1910-14	10	4	0	+	7	2	0	0	+	1
1915-19	27	6	5	+	9	4	1	0	+	1
1920-24	127*	34	8	0	15	2	0	0	0	0
1925-29	291	66	8	15	13	4	3	1	5	0
1930-34	256	50	33	62	29	16	8	0	12	6
1935-39	215	41	31	51	5	19	5	5	15	3
1940-44	156	52	9	34	2	6	11	1	6	5
1945-49	337	200	46	99	25	16	24	1	12	17
1950-54	546	329	133	93	57	65	67	19	26	13
1955-59	665	418	133	172	46	69	94	26	17	11
1960-64	820	670	328	197	123	137	185	72	33	31
1965-69	1109	873	584	141	364	204	252	158	46	68
1970-74	602	827	630	88	300	231	242	202	43	72

1 Some of numbers contain a small proportion of pre-doctoral, post-master degrees.

* In 1920, 1921, 1922, 1923, and 1924, degrees were 7, 4, 37, 45, 34, respectively.

\+ CIT did not function as a collegiate institution until 1921.

In the pre-World War I period almost no doctor's degrees were awarded by engineering schools, as is apparent from Table II. In this period few industrial employers would have known what to do with a man who had a doctor's degree in electrical engineering, beyond ignoring the fact that he was "overeducated."

After the end of World War I, the situation began to change. By this time two new factors had entered the picture. First and most important was the growing importance of the communications field, particularly of the vacuum tube. This technology was sufficiently complex that a year of graduate work added very substantially to the competence of a young man in the communication field. Furthermore, the teachers in communication were typically young and vigorous faculty members, who were themselves exploring and developing the field of communication, and so had interesting projects for bright students who stayed in school beyond the bachelor's degree. A second factor was that by the end of World War I even the older fields of electrical engineering had matured sufficiently to provide subject matter of solid worth—material that was important in the real world but which could not be added to an already crowded four-year undergraduate curriculum. The combined result of these factors was that the period 1920–1942 saw a gradual expansion of enrollment of graduate work in electrical engineering (see Table II).

A careful examination of Table II shows that something obviously happened to M.I.T.'s master's degree program in 1922. The "event" was the graduation of the first class completing M.I.T.'s cooperative program. This was an imaginative arrangement devised through extensive discussions between M.I.T. and several thoughtful leaders at the Lynn works of the General Electric Company, including Elihu Thomson. The cooperative students were a selected group who at the end of their sophomore year were enrolled in a three-year program (including summers) that involved alternating periods of study at M.I.T. and work assignments at the Lynn plant. At the end of five years (including the freshman and sophomore years on campus) these "co-op" students received the bachelor's and master's degrees simultaneously. A unique feature of this program was that during their work periods the co-op students carried at least one regular M.I.T. course taught in the evenings by an M.I.T. faculty member or a General Electric engineer. The reasoning was that in the real world engineers would need to continue to study and they had better start developing the habit of doing so as soon as possible.

This program was extremely successful. In five years of elapsed time it gave the student a far better training than he could get in a four-year bachelor's degree program plus a year and a half of real world experience. Further, it generated enough income to more than finance the additional year involved in the program. In time M.I.T. developed cooperative arrangements with companies in addition to General Electric, and the program continues down into the present.

Although successful from every point of view, the M.I.T. type of cooperative course terminating with the master's degree was not copied by other institutions. The reasons are not

clear, but perhaps lie in the fact that General Electric under Elihu Thomson's influence took a special interest in this particular program. Cooperative programs elsewhere developed in the pattern originated by Herman Schneider at the University of Cincinnati in 1906, which provided a five-year undergraduate program leading to a terminal bachelor's degree.

Although graduate study before 1942 normally meant study for the M.S. degree, an interest in doctoral study began to develop during the 1920's and 1930's. The doctoral students were few in number, but those institutions that had successful master's programs began to accommodate the exceptionally bright and ambitious student who wanted a better foundation in mathematics and fundamental sciences than was provided for in the bachelor's and master's programs, and who wished to obtain research experience. The number of such individuals was not large, as illustrated by Table II, but it nevertheless was a fairly steady trickle that slowly expanded with the years. It will be noted that California Institute of Technology was the first institution in Table II to place emphasis on doctoral studies in electrical engineering.

The typical electrical engineering teacher of the early post-World War I period combined a bachelor's degree in electrical engineering with some practical experience. Very few held a master's degree, and almost none had a doctorate in engineering earned at a U.S. institution. As an illustration, when the author was a graduate student at M.I.T. in 1922–1924, only one member of the electrical engineering faculty of that institution possessed an earned doctor's degree, and only several of those with the rank of Assistant Professor or higher held a master's degree. Of those who held the rank of Instructor (equivalent to today's Assistant Professor), over half held no degree beyond the bachelor's. With the passage of time an increasing number of young Instructors began to work toward the doctorate. Nevertheless, the number of electrical engineering teachers with doctor's degrees was very limited until after World War II.

Academic Research Before World War II

Very little research in electrical engineering was performed on campuses during the earlier days of electrical engineering education. The reasons for this are several: 1) this was a practical age in which acquisition of practical experience was regarded as more important than seeking new knowledge, 2) professors were in general not trained in the basic science of electricity, but rather in the applications of electricity, 3) the "publish or perish" syndrome had not yet been invented, 4) universities had a minimum of laboratory facilities and money for the support of research, 5) interest was heavily on electrical power, and this involved availability of machines of substantial size and cost, 6) there was a lack of graduate students to collaborate and help with the research.[6]

With the passage of time the research situation slowly improved. Islands of real research developed here and there around individual professors. Specialized laboratories dealing with high voltage were established at several institutions and collaborated with power companies on electrical power transmission problems. The developments in communication around the time of World War I and later, including particularly the growing importance of the vacuum tube, gave opportunities for research that were particularly suitable for academic work. Broadcasting was coming up over the horizon, long-distance telephony was increasingly important in communication, public address systems were in common use, talking pictures had arrived, etc. This led to opportunities for new kinds of research, and in addition made knowledge of fundamentals as important as practical experience. Even then it took time to change academia; it was not until after World War II that a substantial fraction of the electrical engineering teachers were regularly engaged in research.

The situation with respect to electrical engineering research on the campus in the mid-1920's is indicated by a survey that the author carried out in 1927.[7] This study showed that in the six-year period 1920–1925 inclusive, there was an average of nine technical papers of college origin per year appearing in the *AIEE Transactions*. This represented virtually the total research output of the nation's teachers of electrical engineering, and of their students, that was deemed of more than temporary value.[8] Approximately seven of these nine papers originated in five institutions; the remaining 100 or more departments of electrical engineering together produced a total of less than two publications per year during this period.

A similar analysis of the *Proceedings of the IRE* for the same period showed less than five publications per year of college origin, and of these over half were credited to physics departments rather than electrical engineering departments. Only one electrical engineering department in the country had more than two papers published in the *Proceedings of the IRE* during the six-year period.

If one considered that a college professor was a productive research worker if he and his students together turned out one technical paper of professional quality every two years, it is found that in the six-year study period there were a total of eight productive research workers on the faculties of the electrical engineering departments in the entire U.S., and that these eight men and their students produced over half of the university research in electrical engineering! Three of these were on the faculty of M.I.T., while the other five were distributed one to a school. Only one of the eight published anything in the *Proceedings of the IRE*.

This may sound almost incredible by present standards, but it highlights the fact that as of the early 1920's teachers taught the existing art of electrical engineering, but did very little to extend that art. It was a situation that offered a marvelous opportunity for an ambitious young faculty member with good training to make a showing. All he needed to do was to write a couple of papers that got published, and he became an important man in his EE department.

Post-World War II

World War II made profound changes in the education of electrical engineers. The war developments such as radar, microwaves, pulse technology, sophisticated control systems, electronic navigation systems, new types of electronic instrumentation, etc., added dimensions to the electrical (electronics) industry that did not die out at the end of the war, but rather continued as permanent additions to the field of

[6] Students receiving the bachelor's degree were commonly required to carry through a project and write a report, but while this gave students valuable "hands-on" experience, it was seldom true research that represented an addition to knowledge.

[7] F. E. Terman, "The electrical engineering research situation in American universities," *Science*, vol. LXV, pp. 385-388, Apr. 22, 1927.

[8] At this time in the history of electrical engineering, the *AIEE Transactions* and the *Proceedings of the IRE* were the only technical journals having substantial professional standing.

electricity. Furthermore, the technological impetus generated by the war continued into the post-war period, and led to such post-war developments as the transistor, integrated circuits, magnetic recording, computers and calculators, guided missiles, communication satellites, the laser, etc. Television displaced radio as the most popular medium of mass entertainment, to be followed by color television.

The result was a virtual explosion of the electrical (electronic) industry. Innumerable new products and devices found a ready reception in the marketplace, and new companies sprang up, first by the hundreds and then by the thousands. Moreover, the tight patent monopoly that had been maintained in the electronics industry through the 1920's and 1930's by RCA, General Electric, Westinghouse, etc., was loosened by the war developments, and the field became essentially open to all comers on reasonable terms.

The exciting developments of the war that triggered off the new electronics were largely the work of physicists temporarily turned engineers. The typical electrical engineer trained in the pre-World War II pattern did not know sufficient fundamental science and mathematics and did not possess the research seasoning to contribute in the creative electrical (electronic) developments of World War II. Engineers were relegated to working out design details, and to following the new equipment through production, test, and installation, but as a group played only a secondary role in the process of generating new ideas.

Those electrical engineering educators who participated in the war developments recognized this situation, and upon returning to their institutions at the end of the war, were forces for upgrading the education of electrical engineers. The times were favorable for doing this. War veterans were anxious to obtain systematic training in the war-time developments. Young men who had worked on war projects were available as teachers, and were not only qualified to teach the new subject matter, but were eager to do so. A scattering of middle-aged faculty members who had participated in the war activities were available to provide leadership for change. Finally, but by no means last, very shortly after the end of the war the government began to support basic research at universities in these new areas of electronics.

As a result of these influences the undergraduate electrical engineering curriculum began gradually but steadily to increase the emphasis on the fundamental science aspects of electrical engineering, particularly physics and mathematics. This was achieved by reducing the time devoted to teaching engineering practice, cutting out subjects that were of little concern to electrical engineers such as surveying, by reducing the intensity of the concentration on 60-Hz power, and by revising the content of many courses.

Master's programs in electrical engineering were developed as direct extensions of the revised bachelor's program, thus making five years of coordinated training available to turn out a well-rounded engineer. The circumstances caused the master's degree gradually to become the degree goal of the student who desired to follow a career in technical electrical engineering, and who sought training that would enable him to work with new ideas that kept coming into electrical engineering.

This new role of the master's degree was accompanied by a change in the character of the associated curriculum. Once the master's degree almost invariably required a thesis project that typically occupied one-third or more of the student's time. However, when the objective became to provide a

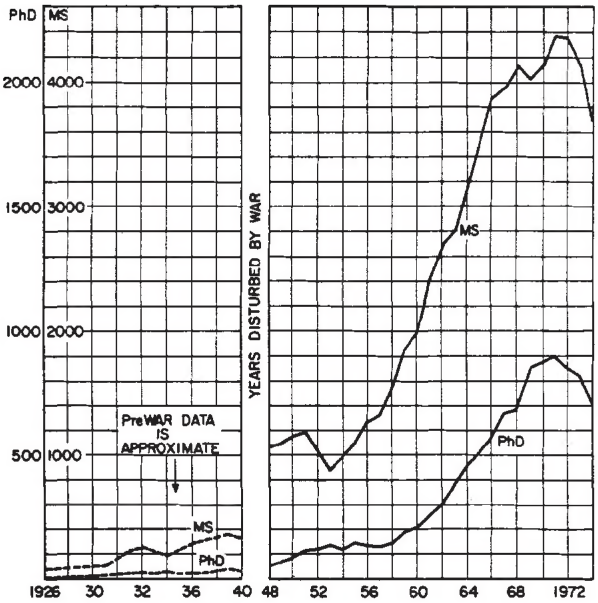

Fig. 1. Graduate degrees awarded in electrical engineering 1926-1974. Data for the pre-World War II years are fragmentary and in some cases estimated, but of the correct order of magnitude.

strong general technical background, most institutions either made the thesis optional or did away with it entirely. The time thereby released was filled with additional course work at graduate or advanced undergraduate level, selected to broaden and strengthen the student's technical and scientific background.

The doctor's degree then became the degree sought by those who wanted training superior to that of their many classmates working for the master's degree, or who planned a career of research in industry, or whose goal was to be a faculty member at an educational institution that had a graduate program.

Under these new conditions, faculty-student research became concentrated at the doctoral level, where the student had the time to perform a really important piece of research, particularly in view of the fact that before embarking on his dissertation the doctoral student would already possess the background provided by the MS course work. This greatly raised the level of faculty-student research being performed on campus.

As shown in Fig. 1, the number of master's and doctor's degrees grew steadily after the war until by the early 1970's approximately a third of the bachelor's degree students went on to a master's degree and approximately 8 percent followed their studies through to the doctor's degree. In contrast, in the early post-war period approximately 10 percent of the bachelor's degree recipients carried their studies to a master's degree, and only a few percent followed through to the doctorate. At the same time, the academic curricula in electrical engineering, including the bachelor's degree program, became steadily both stronger and broader, and by pre-war standards more difficult.

The availability of government research grants and contracts beginning immediately after the end of World War II has had a major impact on electrical engineering education. Such funds have provided the creative faculty man with the resources he needs to work effectively on sophisticated problems of contemporary importance in the real world. They also have enabled him to build up research teams of bright and eager graduate students, who are supported through employment

as part-time research assistants but who simultaneously are also trainees. Research funds likewise have made it possible for the faculty man to work on his research full time during the summer, while receiving summer pay from his research project; this increases both his scholarly productivity and his income.

Thus government sponsored research makes it possible for both faculty and students to perform at a higher level than would otherwise be possible, with corresponding effect on the intellectual tone of the electrical engineering department. In addition, sponsored research supports graduate students while simultaneously giving them a unique and valuable educational experience.

The combined effect of curriculum change, more students carrying on graduate work, and the existence in the university laboratories of electrical engineering research of the highest caliber with participation in this research by doctoral, master's, and sometimes even bachelor's degree candidates, has completely changed both the character and intellectual level of electrical engineering on the campus. This is illustrated by a 1969 meeting of the corporate associates of the American Institute of Physics at which it was postulated: "Engineers now learn enough basic science and mathematics so that they can adequately fill positions once occupied only by physicists." Of the corporate associates present, 82 percent agreed with this statement.[9] It is clear that should another national emergency such as Pearl Harbor occur, electrical engineers will not be found unequal to the challenge as was the case in 1941.

The last twenty-five years have seen increasing interactions develop between universities with strong engineering and industry in geographical proximity to such universities, particularly in electronics. This is not an entirely new phenomenon, as opportunities have traditionally existed for young electrical engineers to improve their competence through enrolling in night courses at nearby institutions and for professors to gain supplementary income through consulting. The difference today is the magnitude of the activity, and the levels at which the interactions take place.

The growing importance of the master's degree has resulted in the widespread development of part-time degree programs structured to suit engineers who have full-time jobs. Various arrangements are used, including courses in the evening, courses offered in the early morning, and courses made available during working hours through live television or videotape. Today practically every center of industrial activity has available some arrangement by which a master's degree in various fields of engineering can be earned by employed engineers.

Faculty interaction with industry has also progressed beyond individual consulting. There are today a number of electrical engineering faculty members around the country who have helped found successful firms, and in some cases have given up teaching to become industrial executives. Furthermore, it is commonplace for high technology companies to have one or more faculty members on their Boards of Directors. In some cases, faculty members have even helped start companies in the role of advisors and/or investors; today there are a number of campuses on which there are one or more unobtrusive electrical engineering professors and ex-professors who are millionaires as a result of knowing which of their graduate students to back with a few thousand dollars worth of consulting assistance, often taken out partially in stock.

The importance of today's electrical engineering departments to high technology industry results largely from the high level of training of electrical engineering faculty members, combined with the opportunities faculty have to sharpen their expertise through well-financed research projects which often generate useful ideas. For example, at Stanford the government sponsored research program in electrical engineering in 1974-1975 accounted for an expenditure of approximately \$6 million. This is to be compared with an expenditure on electrical engineering research of less than \$20 000 per year in the era before World War II, about one-fourth of which was in electronics. No wonder today's electrical engineering faculty operate at a high level and turn out doctorate students who are impressively competent.

The oldest university-industrial complex of importance exists in New England, and is built around M.I.T. and Harvard. Many of the old-line manufacturing companies in the vicinity of Boston have a history that clearly shows important inputs of both personnel and ideas from these institutions. However, the most spectacular university-industrial development is probably that which has grown up on the San Francisco Peninsula around Stanford since the end of World War II. In this case the interactions are quite clear, since they have come into being in a relatively short time and most of the original actors are still alive. Here the contributions that electrical engineering at Stanford has made to the industrial community are quite evident, as are the contributions both intellectual and financial that the contiguous industry has made to the development of a strong electrical engineering department at Stanford.[10]

The best electrical engineering departments of today possess a sophistication and a diversity that gives them much in common with a high technology industrial complex. Each partner in this arrangement benefits from the presence of the other. As a result, one finds that high technology electronic industry tends to be increasingly associated geographically with educational activities.

If one looks at the present world broadly, it is apparent that electricity in its various manifestations is becoming increasingly involved in almost every aspect of our technological civilization and of our daily lives. Today's electrical engineer is being trained in ways that enable him to capitalize on this situation, with the result he can choose between many interesting alternative ways of spending his life. Furthermore, these alternatives characteristically interact with other disciplines. Electrical engineers today are involved not only with such traditional electrical activities as telephony, telegraphy, "wireless," and the generation and distribution of electrical power, but such matters as new sources of energy, optics as represented by the opportunities made possible by fiber optics and by the laser, the mysterious properties of semiconducting materials, medical electronics, computers (from giant computers to pocket calculators), pulse and digital techniques, instruments of almost unbelievable complexity that not only calculate the answers, but even plot the results, etc., etc., seemingly without limit.

Where this will lead is difficult to see, but one thing is certain. This is that electrical engineering is not going to stop advancing. Educators will have to continue to run fast in order

[9] See A. A. Strassenburg, "Supply and demand for physicists," *Physics Today*, vol. 23, pp. 23-28, Apr. 1970.

[10] See Norberg paper, this issue.

to keep even with their field of specialization, and practicing engineers are going to have to spend a certain fraction of their time studying the new knowledge that is being generated by our research oriented academic and industrial laboratories if they are not to become technologically obsolete as they grow older. And never again will electrical engineering have to turn to men trained in other scientific and technical disciplines when there is important work to be done in electrical engineering. Finally, the electrical industry and electrical engineering education is no longer focussed primarily on electrical energy of sinusoidal wave form at 60 ± 0.0000 Hz.

Acknowledgment

Acknowledgment is made to the following persons for helpful discussions and/or information: Arthur Norberg, Coordinator of Science and Technology Project, University of California (Berkeley), Karl Wildes, Massachusetts Institute of Technology, John R. Pierce, California Institute of Technology, and Donald F. Berth, Cornell University.

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